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RESEARCH PAPER

Impact of ice-snow damage on nutrient distribution of a *Cunninghamia lanceolata* woodland

CHEN Feng-xia • FENG Hui-fang • XUE Li •
PAN Lan • XU Peng-bo • LIU Bin

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Abstract: During January to February in 2008, severe ice-snows occurred on 2.09×10^6 km^2 of south China and caused tremendous damage to the forests. Stem damage and crown debris input from the ice-snow in a *Cunninghamia lanceolata* stand in northern Guangdong Province, China, were investigated to determine the extent of ice-snow damage to trees and the nutrient distribution characteristics on woodland. Icicles were produced on branches and leaves of the *C. lanceolata* trees by sleets, resulting in all live trees were damaged by stem breakage. A strong positive correlation was found between the broken position of trees and diameter at breast height (DBH). Nutrient concentrations varied according to components of crown debris. Total nutrient concentration graded in the following order: leaves > stembark > branches > stemwood. Crown debris input from ice-snows was 19.11 t·ha^{-2}, and branches, stemwood, leaves and stembark accounted for 37%, 28%, 27% and 8%, respectively. Nutrient distributions between components of crown debris differed drastically in 2008. The contribution of leaves to total nutrient accumulation of crown debris was 70%, whereas branches, stemwood and stembark contributed 13%, 7% and 10%, respectively. Accumulations of N, P and K by the woodland were 105 067.9 t·ha^{-2} in 2008, and the nutrients of crown debris, litter and the stand soil accounted for 0.18%, 0.03% and 99.79%, respectively. The order of nutrient accumulation in leaves, branches, stembark, stemwood of crown debris and litter was N＞K＞P, but the nutrients stored in the soil were in the order of K > N > P. The N and P concentrations of litter in 2009 were greater than those in 2008, whereas its K concentration was smaller than that of the latter. N and P concentrations of stemwood and stembark in 2009 were slightly greater than those in 2009, whereas their K concentration was smaller than the latter. The N and P accumulations of stemwood and stembark of crown debris in 2009 were close to those in 2008, whereas their K accumulation was slightly smaller than the latter. The N, P and K accumulations of litter in 2009 was greater than those in 2008.

Keywords: crown debris; *Cunninghamia lanceolata*; ice-snow damage; litter; nutrient; soil

Introduction

An extensive ice-snow struck southern China from January to February in 2008. This ice-snow had great impact on forests of 19 provinces, with a damage area of 2.09×10^6 km^2, and was described as the worst of this type in a half century in China. Ice-snow is a natural ecological driver to boreal forests. The ice-snow results in a lot of crown debris, which provides a unique opportunity to gain new and valuable information about forest damage. Since occurrence of ice-snow is limited in special weather and topography, there were relatively few reports about its impact on forests with a focus on tree damage. Bruederle and Stearns (1985) found in studying a Southern Wisconsin Mesic Forest that ice storm damage was uneven and was influenced by topographic and climatic factors. Steven et al. (1991) studied changes in the composition of a *Fagus-Ace*r (Beech-Sugar maple) forest suffering from a severe ice storm disturbance in southeastern Wisconsin and found that canopy opening strongly promoted release of shade-tolerant *Acer saccharum*. Seischab et al. (1993) reported that trees on steep slopes supported asymmetrical ice loads due to their asymmetrical crown structure, which contributed limb breakage. By studying ice storm damage to an old-growth oak-hickory forest in Missouri, Smolnik et al. (1994) found that ice storm had species-specific effects on radial tree growth and yellow poplar was most susceptible to ice storm damage compared with loblolly pine, red oak, and white oak.

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CHEN Feng-xia • FENG Hui-fang • XUE Li (✉) • PAN Lan
XU Peng-bo • LIU Bin
College of Forestry, South China Agricultural University, Guangzhou, 510642, P. R. China. Email: forxue@scau.edu.cn

CHEN Feng-xia
Faculty of Science, University of the Ryukyus, Okinawa 903-0213, Japan. E-mail:

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Rebertus et al. (1997) found that damage levels increased with stem diameter, and trees occupying dominant crown positions were more heavily damaged than suppressed trees. Mou and Warrillow (2000) reported that forests on steep slopes suffered the greatest damage from ice storm. After this ice-snow damage, ice-snow effect on forest has received extensive concern in China (e.g. Luo et al. 2008; Tang et al. 2008; Tian et al. 2008; Xu et al. 2008; Zhao et al. 2008; Zhang et al. 2008).

Stem breakage of forests yields a lot of crown debris in woodlands, which leads to quantification of the changes in pool size and fluxes of nutrients. The crown debris forms a special nutrient distribution pattern and plays a very important role in the fertility of forest soils. The understanding of nutrient distribution of crown debris will help in developing suitable strategies of forest recovery.

Cunninghamia lanceolata (Lamb.) Hook. is a fast growing conifer and one of the most important tree species for timber production in southern China. Many *C. lanceolata* stems were broken by this ice-snow, because a lot of icicles hanged from their leaves and branches. Many attempts have been made to quantify the nutrient distribution (Zhong and Hsiung 1993; Chen 1998), litter (Yang et al. 2004; 2005) nutrient cycling (Feng et al. 1985; Xue 1996; Ma et al. 2007) and soil fertility of *C. lanceolata* stands (Fang 1987; Chen and Chen 2002; Fang and Zhang 2003; Sheng et al. 2003; Sun et al. 2003; Xue et al. 2005a, b; Wang et al. 2005; Luo and Zang 2007; Zhao et al. 2007), but no information is available concerning nutrient distribution of crown debris in *C. lanceolata* woodlands. Such information is important to forest recovery of *C. lanceolata* ecological system, as well as to ensure sustainable development of *C. lanceolata* stands.

The objective of the study was to assess ice-snow damage to a *C. lanceolata* stand in Guangdong Province, China and distribution pattern of nitrogen, phosphorus and potassium in crown debris, litter and soil of the *C. lanceolata* woodland as a consequence of the ice-snow damage. This information will be useful in designing future planning strategies to recover the *C. lanceolata* forest system.

Materials and methods

The studied stand was located in Lechang County (25°09 ′N, 113°30′E), north Guangdong Province, China, which has a subtropical monsoon climate. Mean annual precipitation is 1 522 mm, distributed mostly from April to August. Mean annual temperature is 19.6°C and monthly mean temperature varies from 9.3°C in January to 28.2°C in July.

Field work was carried out in a 17-year-old stand in March 2008. Three plots of 400 m^2 were established. The plots are about 700 m a.s.l. with a 30° slope and a southwesterly exposure (SW 80º20'). The understory coverage was very low, being mainly *Woodwardia Japonica* and *Adiantum capillus-veneris*. The soil under the *C. lanceolata* stand is classified as lateritic red earth.

The diameter at breast height (DBH) and the height of damaged stem of all trees were measured for each plot. Within each replication, six quadrats of 4 m^2 were placed randomly and samples of crown debris and litter in each quadrat were taken, and crown debris was separated into branches, leaves, stem wood and stem bark for weight calculations. Subsamples were taken to laboratory and dried to constant weight at 80°C for measuring dry weight and ground in a mill containing 1 mm stainless steel screen for nutrient analysis.

Within each plot, five soil samples in 0–40 cm were collected from randomly located points and combined to form a composite sample for the nutrient analyzed of stand soil. The air-dried soil samples were sieved (aggregates were broken to pass through a 0.25 mm mesh for total N and a 0.15 mm mesh for total P and total K measurements); The total nitrogen was measured using a semi Micro-Kjeldhal technique (Bremner and Mulvaney 1982). Total P was determined by molybdenum blue colorimetry and total K was determined by atomic absorption spectroscopy following NaOH digestion (Lu 2000). All chemical analyses were carried out in triplicate.

In March 2009, the crown debris, litter and soil were sampled and analyzed according to the same methods used in 2008.

Results

Relationship between diameter at breast height and height of damaged stems

The diameters at breast height (DBH) of damaged stems ranged from 2.2 to 25.8 cm with an average of 13.6 cm, whereas the height of damaged stems ranged from 1.5 to 16 m with an average of 7.7 cm (Fig. 1). Breakage points of stems with big DBH were high, whereas those of stems with small DBH were low, and the DBH and height of damaged stems yielded a significantly positive relationship (p<0.001).

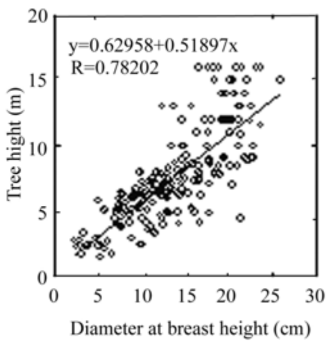

Fig. 1 Relationship between diameter at breast height and height of damaged stems

Nutrient concentrations in the *C. lanceolata* woodland

Nutrient concentrations in the *C. lanceolata* wooodland in 2008 varied according to component (Table 1). At all components and litter, the highest concentrations of N, P and K were found in leaves, and the lowest concentrations of N and K, and the lowest

P concentration existed in stem wood and branches, respectively. N concentration was considerably higher in stembark and litter when compared with branches and stemwood, and P concentration decreased in the order of leaves > stembark>litter> branches > stemwood, while K concentration and total nutrient concentration graded in the following order: leaves > stembark > litter > branches > stemwood. The nutrient concentration was K > N > P in the stembark and N > K > P for other crown debris and litter.

Compared to crown debris and litter, soil had lower N concentration, median P concentration, and high K concentration. The nutrient concentrations of soil with 0–20 cm were higher than those of soil with 20–40 cm.

Table 1. Nutrient concentrations in the *C. lanceolata* wooodland in 2008

components		N（mean±SD）($g \cdot kg^{-1}$)	P（mean±SD）($g \cdot kg^{-1}$)	K（mean±SD）($g \cdot kg^{-1}$)	Total ($g \cdot kg^{-1}$)
Crown debris	Branches	1.843±0.077	0.168±0.002	1.545±0.019	3.556
	Leaves	15.400±0.175	1.183±0.034	9.365±0.028	25.948
	Stemwood	1.409±0.015	0.143±0.002	0.758±0.008	2.310
	Stembark	5.535±0.222	0.575±0.011	5.854±0.109	11.964
Litter		6.385±0.030	0.358±0.007	2.881±0.022	9.624
Soil (0–20 cm)		2.344±0.027	0.611±0.008	20.087±0.129	23.042
Soil (20–40 cm)		1.863±0.032	0.561±0.005	18.973±0.125	21.397

Branches and leaves of crown debris in 2008 became litter after one year, leading to a greater N and P concentrations in litter in 2009, whereas its K concentration was smaller than that in 2008 (Table 2), which may be caused by rain leaching. N and P concentrations of stemwood and stembark in 2009 were slightly higher than those in 2008, whereas their K concentration was lower than the latter. N concentration of soil was higher at 0–20 cm layer and lower at 20–40 cm layer, P concentration was higher and K concentration was lower in the two soil layers compared to those in 2008.

Table 2. Nutrient concentrations in the *C. lanceolata* wooodland in 2009

components	N（mean±SD）($g \cdot kg^{-1}$)	P（mean±SD）($g \cdot kg^{-1}$)	K（mean±SD）($g \cdot kg^{-1}$)	Total ($g \cdot kg^{-1}$)
Stemwood of crown debris	1.465±0.013	0.153±0.002	0.667±0.010	2.285
Stembark of crown debris	5.812±0.184	0.615±0.007	5.034±0.124	11.461
Litter*	9.174±0.076	0.607±0.009	0.910±0.021	10.691
Soil (0–20 cm)	2.628±0.017	0.653±0.002	15.860±0.221	19.141
Soil (20–40 cm)	1.588±0.015	0.591±0.005	16.490±0.154	18.669

* Litter contains branches and leaves of crown debris in 2008

Nutrient distribution in crown debris of *C. lanceolata* stand

On account of concentration differences between components, dry weight and nutrient concentration distributions differed drastically. Dry weight allocation of the crown debris was as follows: branches > stemwood > leaves > stembark; Branch weight comprised 37% of the total weight, whereas stembark only accounted for 8% in 2008 (Table 3). Nutrient accumulation varied among the different components. Leaves represented the largest compartment of total nutrients. A particularly large proportion, over 67%, of total N, P, and K of the crown debris was found in leaves, branches were the second largest compartment of N, P and K. High N concentrations in leaves, coupled with relatively high leaf dry weight, resulted in leaves being the largest compartment (about 70%) of total nutrient. Though concentrations of nutrients in branches were low relative to leaves, its dry weight was high, making them the second large compartment of total N, P and K. Stembark accounted for a particularly small proportion of total weight (8%), but its nutrient concentration was higher than that of stemwood, as a result its N, P and K accumulations were greater than the latter. For a corresponding dry weight percentage of about 28%, the contribution of stemwood to total nutrient accumulation was only 7% for N, 9% for P and 6% for K due to its low nutrient concentration.

Table 3. Crown debris ($t \cdot ha^{-1}$) and nutrient amounts ($kg \cdot ha^{-1}$) and distribution ratio (%)

	Dry weight	N	P	K	Total
Branches	7.12 (37%)	13.1 (12%)	1.2 (13%)	11.0 (15%)	25.3 (13%)
Leaves	5.14 (27%)	79.1 (73%)	6.1 (68%)	48.1 (67%)	133.3 (70%)
Stemwood	5.36 (28%)	7.5 (7%)	0.8 (9%)	4.1 (6%)	12.4 (7%)
Stembark	1.51 (8%)	8.4 (8%)	0.9 (10%)	8.8 (12%)	18.1 (10%)
Total	19.11 (100%)	108.1 (100%)	9.0 (100%)	72.0 (100%)	189.1 (100%)

Nitrogen accumulation ranged from 7.5 to 79.1 $kg \cdot ha^{-1}$ with a

total storage of 108.1 kg·ha^{-1} among components, phosphorous storage was lowest among the nutrients studied, which stored in leaves was 6.1 kg·ha^{-1}, followed by branch (1.2 kg·ha^{-1}), stembark (0.9 kg·ha^{-1}) and stemwood (0.8 kg·ha^{-1}). Potassium was mainly contributed by leaves (67%). Total storage of potassium was 72.0 kg·ha^{-1} ranging between 4.1 and 48.1 kg·ha^{-1}.

Accumulation of nutrients in the *C. lanceolata* woodland

The stores of nutrients in soil and different biomass fractions of the *C. lanceolata* woodland in 2008 are shown in Table 4. Over 98% of the nutrients were in soil. Crown debris accounted for 1.08%, 0.32% and 0.08% for N, P, K, respectively, whereas each nutrient stored in litter accounted for less than 0.25%.

Table 4. Accumulation and distribution of nutrients and distribution ratio in the *Cunninghamia lanceolata* woodland in 2008

Components	Dry weight (t·ha^{-1})	Nutrients (kg·ha^{-2}) N	P	K	Total
Crown debris	19.11	108.1 (1.08%)	9.0 (0.32%)	72.0 (0.08%)	189.1 (0.18%)
Litter	3.72	23.7 (0.24%)	1.3(0.05%)	10.7 (0.01%)	35.8 (0.03%)
Soil (0–40 cm)		9918.9 (98.68%)	2764.9 (99.63%)	92159.3 (99.91%)	104843.1 (99.79%)
Total		10050.7 (100%)	2775.1 (100%)	92241.7 (100%)	105067.9 (100%)

The N and P accumulations of stemwood and stembark of crown debris in 2009 were close to those in 2008, since dry weight, N and P concentrations of stemwood and stembark in 2009 were close to those in 2008, whereas their K accumulation was slightly smaller than the latter (Table 5). The N, P and K accumulations of litter in 2009 was greater than those in 2008 due to great litter accumulation of the former. Soil accounted for more than 98% of each nutrient in the woodland in 2009.

Table 5. Accumulation and distribution of nutrients and distribution ratio in the *Cunninghamia lanceolata* woodland in 2009

Components	Dry weight (t·ha^{-1})	Nutrient (kg·ha^{-1}) N	P	K	Total
Stemwood of crown debris	5.15	7.6 (0.08%)	0.8 (0.03%)	3.4 (0.01%)	11.8 (0.02%)
Stembark of crown debris	1.46	8.8 (0.10%)	0.9 (0.03%)	7.6 (0.01%)	17.3 (0.02%)
Litter	9.95	91.3 (1.00%)	6.0 (0.22%)	9.1 (0.01%)	106.4 (0.13%)
Soil (0–40 cm)		9057.4 (98.82%)	2733.7 (99.72%)	71651.0 (99.97%)	83442.1 (99.83%)
Total		9165.1 (100%)	2741.4 (100%)	71671.1 (100%)	83571.6 (100%)

Discussion

Damage from the ice-snow is very serious, resulting in 100% canopy loss of the *C. lanceolata* stand, indicating this tree species is more likely to break once the resistance of the wood has been exceeded, although they are more capable of supporting ice accumulation. The most relevant wood property related to resistance is the maximum bending load to failure, which pronounced reduction with slight decrease in specific gravity (Bragg et al. 2003). Specific gravity can vary within a species and even along the dimensions of an individual tree. The very significant correlation between DBH and height of damaged stems indicates that breakage height of stems increases with increasing DBH, and stems occupying dominant crown position have higher breakage point than suppressed trees. Big stems support more ice loads due to their big crown. With increase of ice weight on branches and leaves of stems, the stems bend at points below crown with the aid of themselves elasticity. The higher individuals are, the higher their crown places at stems are. Trees break at the point along the stem where the accumulated stress exceeds the tree's resilience to damage for a tree of a given size and species (Peltola et al. 1999).

Because broken position of trees was below crown, leading a lot of crown debris in 2008, and big individual contributes more nutrients to the *C. lanceolata* woodland than the smaller one due to greater crown of the former. Crown debris contributed nutrients of 189 kg·ha^{-1} with N of 108.1, P of 8.9 and K of 72 kg·ha^{-1}, which was the similar to the result of a *C. lanceolata* stand on a poor site (Xue 1996), but lower than nutrients in the *C. lanceolata* stands reported by Feng et al. (1985) and Chen (1998). The nutrient storage mainly depends on biomass accumulation and nutrient concentration in different components. In the present study, crown debris amount is low and thus results in poor nutrient accumulation.

As a natural ecological driver of forests, the ice-snow damage changes nutrient distribution of the *C. lanceolata* stand. The nutrients contained crowns transfer to woodland. The open canopy resulting from ice-snow damage creates a mosaic of microclimates that affect decomposition processes. Solar radiation can potentially affect decomposition by altering microbial community composition, extracellular enzyme activity or litter characteristics (Gallo et al. 2009). The ultraviolet radiation of solar radiation generally increases mass decomposition (Brandt et al. 2007; Day et al. 2007).

Among the different components of crown debris, branches and leaves decompose faster than stemwood and stembark. The formers contained smaller concentrations of cellulose and lower

concentration of lignin compared with the latter. Greater cellulose concentration is not favorable to decomposition, and the presence of lignin restricts microbial colonization, leading to inhibition of wood decomposition (Baldock et al. 1997). In the *C. lanceolata* stand suffering from ice-snow damage, stemwood and stembark formed a significant proportion of the crown debris. The rate of decomposition and nutrient release from stemwood and stembark is relatively slow, resulting in the slow release rate of nutrients and making decomposing stemwood and stembark an important long-term source of nutrients and carbon sink. This might contribute to sustain the productivity of stand soil.

In the short term, ice-snow disturbance may improve nutrient status in the woodlands. This is attributed to increase radiation reaching the forest floor due to loss of canopy, probably also increased the soil temperature, which has a positive effect on mineralization. Ice-snow damage also increases inputs of relatively labile carbon to the forest floor in the form of crown detritus, which leads to increasing rates of soil litter decomposition. Decomposition of crown debris releases nutrients for cycling within the stand and provides carbon and nutrients to other organisms. However, in the long-term, ice-snow disturbance can reduce woodland nutrients because damaged stems have few leaves and there will be little litter return to soil, which will cause a decline in soil fertility. On the other hand, loss of crowns can promote the growth of understory, litter from understory will increase, which may compensate litter loss from trees to a certain extent. Meanwhile, high sunlight radiations cause a dramatic drop in water availability in crown debris and litter layer, and forest fire is easily to cause. Forest fire lead to an increase in soil fertility in a short-term, but soil erosion will occur as rain on soil surface, which will lead to a decrease of nutrient reserves. Therefore, long-term biogeochemical monitoring in the stand is necessary in order to detect the overall and long-term changes of soil fertility.

References

Baldock JA, Sewell T, Hatcher PG. 1997. Decomposition induced changes in the chemical structure of fallen red pine, white spruce and Tamarack logs. In: Cadisch G, Giller KE (Eds.), Driven by Nature: Plant Litter Quality and Decomposition. CAB International, Wallingford.

Brandt LA, King JY, Milchunas DG. 2007. Effects of UV radiation on decomposition depend on precipitation and litter chemistry in a shortgrass steppe ecosystem. *Global Change Biol*, **13**: 2193–2205.

Bragg DC, Sheltona MG, Zeide B. 2003. Impacts and management implications of ice storms on forests in the southern United States. *For Ecol Manage*, **186**: 99–123.

Bremner JM, Mulvaney CS. 1982. Nitrogen-total. In: Page AL, Miller RH and Keeney RR (Eds), Methods of Soil Analysis, Part 2. seconded. Madison, WI: American Society of Agronomy, pp. 595–624.

Bruederle LP, Stearns FW. 1985. Ice Storm Damage to a Southern Wisconsin Mesic Forest. *Bull Torrey Bot Club*, **112**: 167–175.

Chen Hongjun. 1998. Biomass and nutrient distribution in a Chinese fir plantation chronosequence in southwest Hunan, China. *For Ecol Manage*, **105**: 209–216.

Chen Saoquan, Chen Shurong. 2002. Functions of the mixed forest of *Cunninghamia lanceolata* and *Schima superba* in water conservation and soil fertility buildup. *Acta Pedol Sin*, **39**(4): 599–603. (in Chinese)

Day TA, Zhang ET, Ruhland CT. 2007. Exposure to solar UV-B radiation accelerates mass and lignin loss of *Larrea tridentata* litter in the Sonoran Desert. *Plant Ecol*, **193**: 185–194.

Fang Lejin, Zhang YunBin. 2003. Studies on fertility changes of young fir forestry. *Acta Pedol Sin*, **40**(2): 316–319. (in Chinese)

Fang Qi. 1987. Effects of continued plating of Chinese fir on the fertility of soil and the growth of stands. *Sci Silv Sin*, **23**(4): 389–397. (in Chinese)

Feng Zongwei, Chen Chuyin, Wang Kaiping, Zhang Jiawu, Zeng Shiyu, Zhao Jilu, Deng Shijian. 1985. Accumulation, distribution and cycling of nutrient elements in a subtropical Chinese fir stand. *Acta Phytoecol Geobot Sin*, **9**: 245–255. (in Chinese)

Gallo ME, Porras-Alfaro A, Odenbach KJ, Sinsabaugh RL. 2009. Photoacceleration of plant litter decomposition in an arid environment. *Soil Biol Biochem*, **41**:1433–1441.

Lu Rukun. 2000. Analytical Methods of Soil and Agricultural Chemistry. Beijing: China Agricultural Science and Technology Press. (in Chinese)

Luo Tushou, Zhang guoping, Wu hongming, Weng Qijie, Luo Xinhua, Zhang Na, Xiao Yihua, Zeng Fanzhu, Wang Xu, Yu Weisheng, Zhao Xia. 2008. Effects of the frozen rain and snow disaster to the litterfall of evergreen and deciduous broadleaved mixed forest in Yangdongshan Shierdushui Nature Reserve of Guangdong. *Sci Silv Sin*, **44**(11): 177–183. (in Chinese)

Luo YunJian, Zhang Xiaoquan. 2007. The assessment of soil degradation in successive rotations of Chinese fir plantation and the soil amelioration of mixed plantation of Chinese fir and broad-leaved. *Acta Ecol Sin*, **27**(2): 715–724. (in Chinese)

Ma Xiangqing, Heal KV, Liu Aiqin, Jarvis PG. 2007. Nutrient cycling and distribution in different-aged plantations of Chinese fir in southern China. *For Ecol Manage*, **243**: 61–74.

Mou P, Warrillow MP. 2000. Ice storm damage to a mixed hardwood forest and its impacts on forest regeneration in the ridge and valley Region of Southwestern Virginia. *J Torrey Bot* Soc, **127**: 66–82.

Peltola H, Kellomäki S, Väisänen H, Ikonen V-P. 1999. A mechanistic model for assessing the risk of wind and snow damage to single trees and stands of Scots pine, Norway spruce, and birch. *Can J For Res*, **29**: 647–661.

Rebertus AJ, Shifley SR, Richards RH, Roovers LM. 1997. Ice storm damage to an old-growth oak-hickory forest in Missouri. *Am Midi Nat*, **137**: 48–61.

Seischab FK, Bernard JM, Eberle MD. 1993. Glaze storm damage to Western New York forest communities. *Bull Torrey Bot Club*, **120**: 64–72.

Sheng Weitong, Yang Chengdong, Fan Shaohui. 2003. Variation of soil properties of Chinese fir plantation. *For Res*, **16**(4): 377–385. (in Chinese)

Smolnik M, Hessl A, Colbert JJ. 2006. Species-specific effects of a 1994 ice storm on radial tree growth in Delaware**.** *J Torrey Bot Soc*, **133**: 577–584.

Steven DD, Kline J, Matthiae PE. 1991. Long-term changes in a Wisconsin *Fagus–Acer* forest in relation to glaze storm disturbance. *J Veg Sci*, **2**: 208–210.

Sun Qiwu,Yang Chengdong, Jiao Ruzhen. 2003. The changes of soil properties of the successive Chinese fir plantation in Dagang Mountain of Jiangxi Province. *Sci Silv Sin*, **39**(3): 1–6. (in Chinese)

Tang Jingming, Song Congwen, Dai Junhua, Liu Henggui, Zhen Xiaoyan. 2008. Investigation on the frozen snow damage of main afforestation tree species in Hubei Province. *Sci Silv Sin*, **44**(11): 2–10. (in Chinese)

Tian Dalun, Gao Shuchao, Kang Wenxing, Yan Wende, Xiang Wenhua, Fang Xi. 2008. Impact of freezing disaster on nutrient content in a *Koelreuteria*

paniculata and *Elaeocarpus decipens* mixed forest ecosystem. *Sci Silv Sin*, **44**(11): 115–122. (in Chinese)

Wang Hua, Huang Yu, Huang Huang, Wang Ke M, Zhou Shang Y. 2005. Soil properties under young Chinese fir-based agroforestry system in mid-subtropical China. *Agrofor Syst*, **64**: 131–141.

Xu Yezhou, Sun Xiaomei, Song Congwen, Du Chaoqun, Chen Bairu, Zhang Dingqing. 2008. Damage of sub-alpine *Larix kaempferi* plantation induced by snow storm in Western Hubei. *Sci Silv Sin*, **44**(11): 11–17. (in Chinese)

Xue Li. 1996. Nutrient cycling in a Chinese fir stand on a poor site in Yishshan, Guanxi. *For Ecol Manage*, **89**: 115–123

Xue Li, Wu Min, Xu Yan, Li Yan, Qu Min. 2005a. Soil nutrients and Microorganisms in soils of typical plantations in South China. *Acta Pedol Sin*, **42**(6): 1017–1023. (in Chinese)

Xue Li, Xiang Wenjing, He Yuejun, Li Yan, Wu Min, Xu Yan, Qu Ming. 2005b. Effects of different ground clearance on soil fertility of Chinese fir stands. *Chin J Appl Ecol*, **16**(8): 1417–1421. (in Chinese)

Yang Yusheng, Guo Jianfen, Chen Guangshui, Xie Jinsheng, Gao Ren, Cai Liping, Lin Peng. 2004. Litterfall, nutrient return and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China. *Ann For Sci*, **61**: 465–476.

Yang Yusheng, Guo Jianfen, Chen Guangshui, Xie Jinsheng, Gao Ren, Li Zhen, Jin Zhao. 2005. Litter production, seasonal pattern and nutrient return in seven natural forests compared with a plantation in southern China. *Forestry*, **78**: 403–415.

Zhang Jianguo, Duan Aiguo, Tong Shuzhen, Sun Honggang, Deng Zongfu, Zhang Shougong. 2008. Harm of frost and snow suppress to near mature stands of *Cunninghamia lanceolata* plantations. *Sci Silv Sin*, **44**(11): 18–22.

Zhao Meng, Fang Xi, Tian Dalun. 2007. Relation between the quantity of soil microbe and soil factor in the second rotation Chinese fir plantation. *Sci Silv Sin*, **43**(6): 7–12. (in Chinese with an English abstract)

Zhao Xia, Shen Xiaoqing, Huang Shineng, Luo Xinhua, Luo Tushou, Zeng Fanzhu, Zhang Na, Yu Weisheng, Xiao Yihua, Wang Xu. 2008. Mechanical damages to woody Plants from a snow disaster in Yangdongshan Shierdushui Provincial Nature Reserve. *Sci Silv Sin*, **44**(11): 164–167.

Zhong Anliang, Hsiung Wenyue. 1993. Evaluation and diagnosis of tree nutritional status in Chinese fir plantations, Jiangxi, China. *For Ecol Manage*, **62**: 245–270